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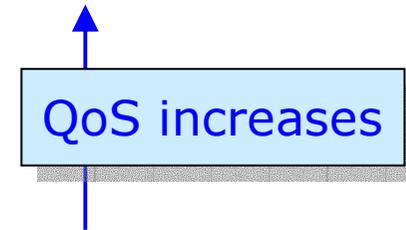
OFDM PHY layer

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Four service classes

The IEEE 802.16 MAC layer defines four service classes:

- Unsolicited Grant Service (UGS)
- Real-time Polling Service (rtPS)
- Non-real-time Polling Service (nrtPS)
- Best Effort (BE) service

QoS increases

The scheduling algorithms needed for implementing the three first types of services are implemented in the BS (while allocating uplink bandwidth to each SS) and are not defined in the 802.16 standard. Each SS negotiates its service policies with the BS at the connection setup time.

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Unsolicited grant service (UGS)

UGS
rtPS
nrtPS
BE

UGS offers fixed size grants on a real-time periodic basis, which eliminates the overhead and latency of SS requests and assures that grants are available to meet the flow's real-time needs. The BS provides fixed size bursts in the uplink at periodic intervals for the service flow. The burst size and other parameters are negotiated at connection setup.

Typical UGS applications: E1/T1 links (containing e.g. delay-sensitive speech signals), VoIP (without silence suppression).

Real-time Polling Service (rtPS)

UGS
rtPS
nrtPS
BE

The Real-time Polling Service (rtPS) is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as VoIP (with silence suppression) or streaming video.

This service offers real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired uplink transmission burst. This service requires more request overhead than UGS, but supports variable grant sizes for optimum data transport efficiency.

Non-real-time Polling Service (nrtPS)

| UGS |
|-----|
| rtPS |
| **nrtPS** |
| BE |

The Non-real-time Polling Service (nrtPS) is designed to support non-real-time service flows that require variable size bursts in the uplink on a regular (but not strictly periodic) basis.

Subscriber stations contend for bandwidth (for uplink transmission) during contention request opportunities. The availability of such opportunities is guaranteed at regular intervals (on the order of one second or less) irrespective of network load.

Best Effort (BE) service

| UGS |
| rtPS |
| nrtPS |
| BE |
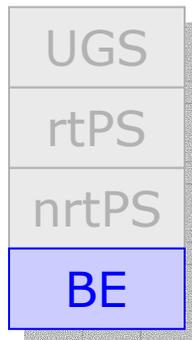
The Best Effort service is intended to be used for best effort traffic where no throughput or delay guarantees are provided.

Subscriber stations contend for bandwidth (for uplink transmission) during contention request opportunities. The availability of such opportunities depends on network load and is not guaranteed (in contrast to nrtPS).

Radio Link Control in IEEE 802.16

The main task of Radio Link Control (RLC) in IEEE 802.16 systems is to provide dynamic changing of UL and DL burst profiles on a per-connection and per-frame basis, depending on radio channel characteristics and QoS requirements.

As an example, RLC provides signaling for initial access (ranging) and bandwidth allocation in the downlink direction:

- Ranging request (RNG-REQ) from SS to BS
- Ranging response (RNG-RSP) from BS to SS
- Bandwidth requests (DBPC-REQ) from SS to BS
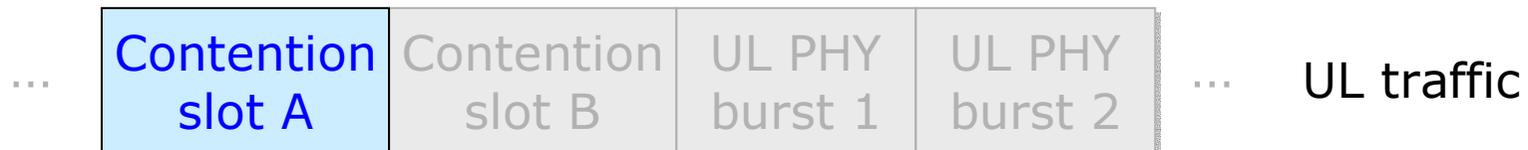- Bandwidth confirmation (DBPC-RSP) from BS to SS

Initial access (initial ranging)

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

During initial access, the SS sends a ranging request message in the contention slot reserved for this purpose, among others indicating which kind of DL burst profile should be used.

Note: There is the possibility of collision since other subscriber stations also send ranging request messages in this contention slot.
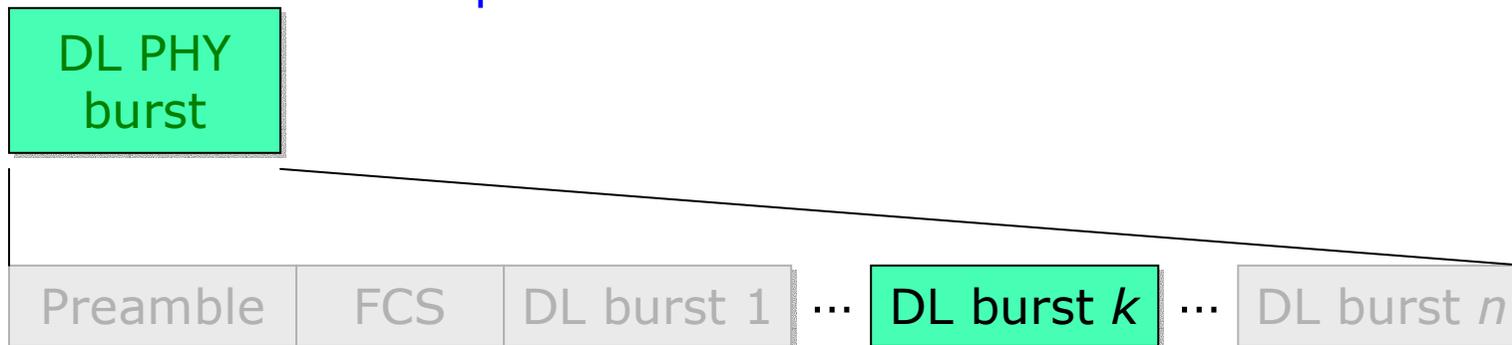
| ... | Contention slot A | Contention slot B | UL PHY burst 1 | UL PHY burst 2 | ... | UL traffic |

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Initial access (initial ranging)

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

In response to the RNG-REQ message, the BS returns a ranging response message in a DL burst with a sufficiently robust burst profile.

This message includes the timing advance value for correct alignment of bursts in UL, as well as UL power control information.

DL PHY burst

| Preamble | FCS | DL burst 1 | ··· | DL burst *k* | ··· | DL burst *n* |

DL burst profile change

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

The SS continuously measures the radio channel quality. If there is a need for change in DL burst profile, the SS sends a DL burst profile change request message in the contention slot reserved for this purpose, indicating the desired new DL burst profile.

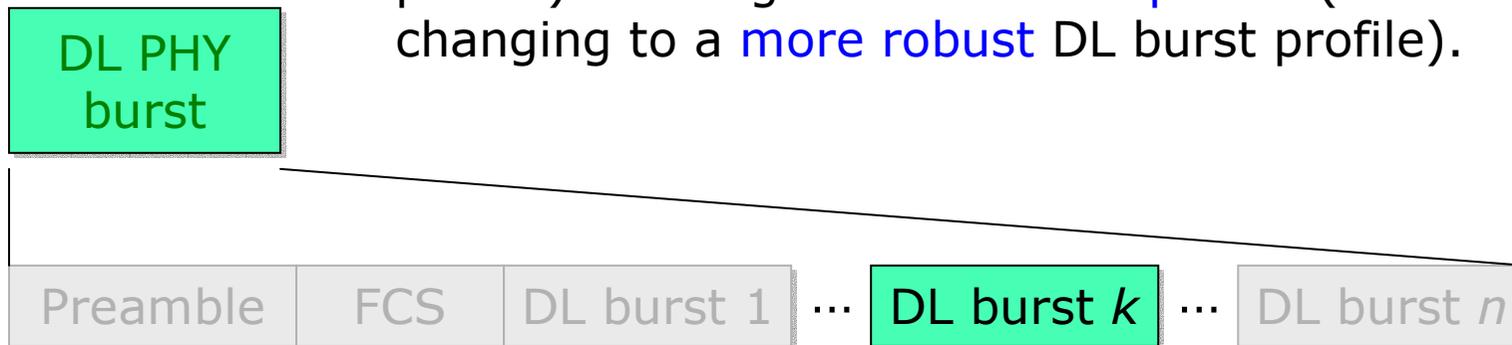| ... | Contention slot A | Contention slot B | UL PHY burst 1 | UL PHY burst 2 | ... | UL traffic |

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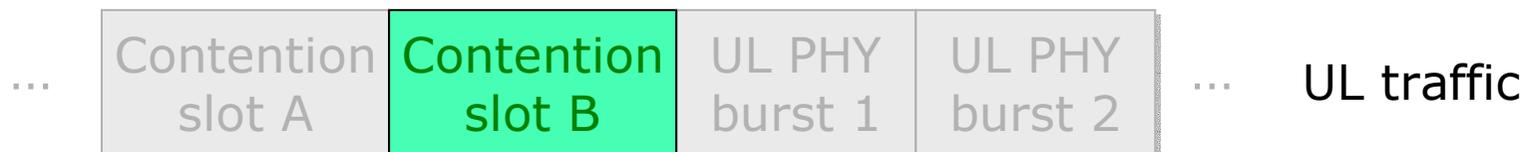
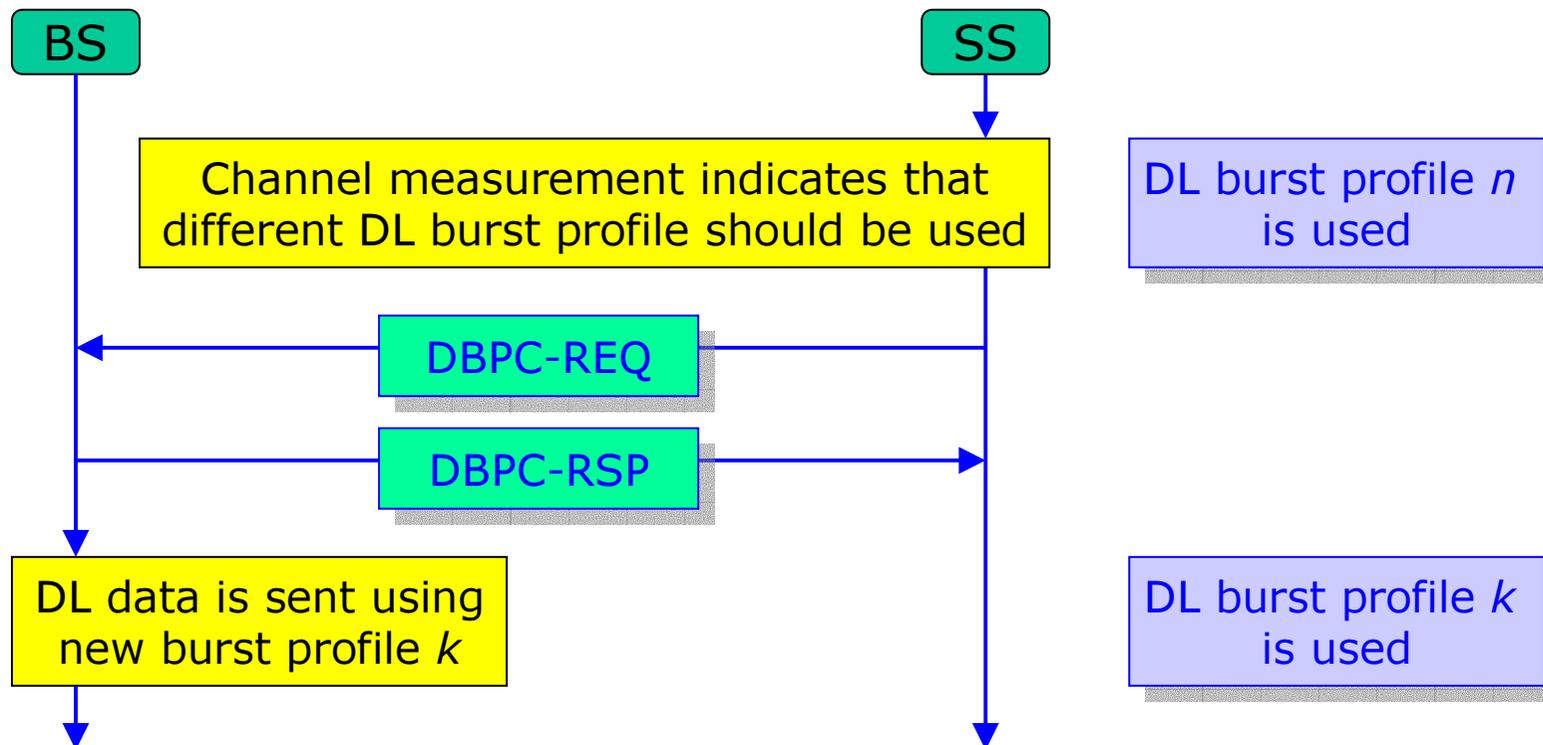# DL burst profile change

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP

In response to the DBPC-REQ message, the BS returns a DL burst profile change response message confirming the new burst profile.

This is done in a DL burst with the old burst profile (when changing to a less robust DL burst profile) or using the new burst profile (when changing to a more robust DL burst profile).

DL PHY burst

Preamble	FCS	DL burst 1	···	DL burst *k*	···	DL burst *n*

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Transition to a new DL burst profile

BS

SS

Channel measurement indicates that different DL burst profile should be used

DL burst profile n is used

DBPC-REQ

DBPC-RSP

DL data is sent using new burst profile k
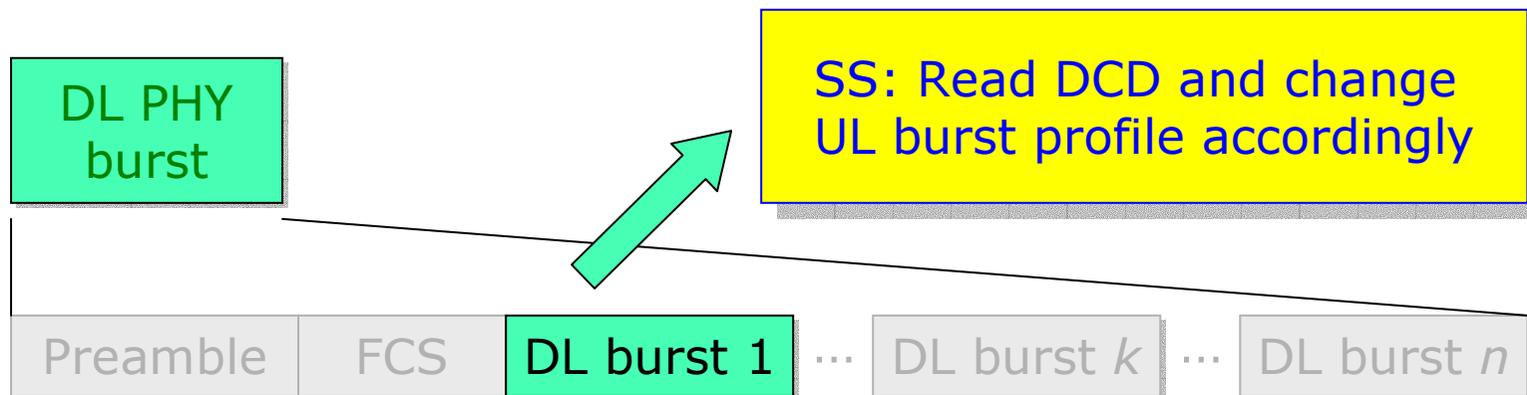
DL burst profile k is used

UL burst profile change

RNG-REQ
RNG-RSP
DBPC-REQ
DBPC-RSP
DCD

The BS measures the UL signal quality and may request a change in UL burst profile as indicated in the downlink channel descriptor (DCD) within the first DL burst of the DL PHY burst.

DL PHY burst

SS: Read DCD and change UL burst profile accordingly

| Preamble | FCS | DL burst 1 | ⋯ | DL burst k | ⋯ | DL burst n |

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Dynamic QoS management in practice

The request-response mechanism described on the previous slides is designed to be scalable, efficient, and self-correcting.

While extensive bandwidth allocation and QoS mechanisms are specified in the IEEE 802.16 standard, the details of scheduling and reservation management have not been standardized and thus provide an important mechanism for vendors to differentiate their equipment.

(There is a similar situation regarding standardization of a transmission system in general: the transmitted signal is standardized in detail, whereas receivers can process the received signal as they like, using innovative technology.)

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Three types of management connections

When a subscriber station acesses the network, three types of management connections are established between the SS and the BS (before transport connections can be established):

- Basic management connection for exchange of short, delay-critical MAC management messages

- Primary management connection for exchange of longer, more delay tolerant MAC management messages

- Secondary management connection for exchange of delay tolerant IP-based messages, such as used during DHCP transactions.

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Connection establishment (1)

Channel acquisition:

The MAC protocol includes an initialization procedure designed to eliminate the need for manual configuration.

Upon installation, the SS scans for a suitable BS downlink signal. The SS synchronizes to this signal and reads the downlink channel descriptor (DCD) and uplink channel descriptor (UCD) information in the first DL burst of the DL PHY PDU, in order to learn the modulation and coding schemes used on the carrier.

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Connection establishment (2)

Initial ranging and negotiation of SS capabilities (1):

Upon learning what parameters to use for its initial ranging signal in UL, the SS looks for initial ranging opportunities by scanning the UL-MAP information present in every frame.

After a random backoff time, the SS sends the ranging request message (RNG-REQ) to the BS.

The BS calculates the timing advance value that the SS must use in UL from now on, and sends this information to the SS in the RNG-RSP message.

Connection establishment (3)

Initial ranging and negotiation of SS capabilities (2):

The BS also sends power control information, as well as the CID for the basic management connection and the primary management connection to the SS.

Using the primary management connection, the SS reports its PHY capabilities, including the modulation and coding schemes it supports and whether, in an FDD system, it is half-duplex or full-duplex. The BS, in its response, can deny the use of any capability reported by the SS.

Connection establishment (4)

SS authentication (using privacy sublayer):

Each SS contains both a manufacturer-issued factory-installed X.509 digital certificate and the certificate of the manufacturer. After sending these certificates (and the public key of the SS) to the BS, the BS can authenticate the SS. If authentication is successful, the BS sends the Authorization Key (AK), encrypted with the public key of the SS, to the SS.

The AK is used both by SS and BS for securing further information flow.

Connection establishment (5)

SS registration:

Upon successful authentication, the SS registers with the network. The response from the BS contains the CID for a secondary management connection. Contrary to the basic and primary management connection, this secondary management connection is secured.

At this point, the capabilities related to connection setup and MAC operation, as well as the IP version used, are determined. (Remember that the secondary management connection is IP-based.)

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Connection establishment (6)

IP connectivity:

After registration, using the secondary management connection, the SS is allocated an IP address via DHCP and establishes the time of the day via the Internet Time Protocol.

The DHCP server also provides the address of the TFTP server from which the SS can request a configuration file. This file provides a standard interface for providing vendor-specific configuration information.

Connection establishment (7)

Connection setup:

Finally, the secondary management connection is also used for setting up one or more transport connections. These transport connections carry the actual user data (IP traffic, VoIP traffic, etc.) between BS and SS.

IEEE 802.16 uses the concept of service flows to define unidirectional transport of packets on either downlink or uplink. Service flows are characterized by a certain set of QoS parameters, and are established using a three-way handshaking establishment procedure.

Summary: Dynamic QoS management

In summary, IEEE 802.16 offers the following mechanisms for dynamically managing QoS and bandwidth:
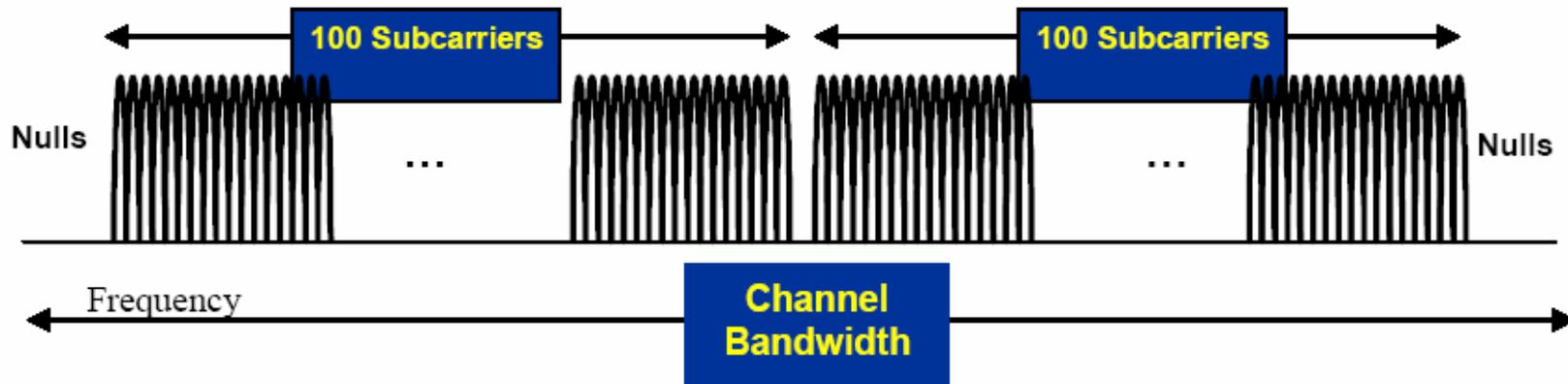
In the PHY layer by adjusting the DL and UL burst profiles (modulation and coding combination) on a per-frame basis.

In the MAC layer through fragmentation and packing (both can be done at the same time).

At higher protocol layers by using scheduling algorithms in the base station. These algorithms are not specified in the IEEE 802.16 standard.

WirelessMAN-OFDM PHY

WirelessMAN-OFDM is based on 256 subcarriers, of which 200 subcarriers are used: 192 data subcarriers + 8 pilot subcarriers. There are 56 "nulls" (center carrier, 28 lower frequency and 27 higher frequency guard carriers).

Modulation and coding affect user data rate

The 192 data subcarriers carry 192 data symbols in parallel (= transmitted at the same time). Each symbol carries 1 bit (BPSK), 2 bits (QPSK), 4 bits (16-QAM), or 6 bits (64-QAM) of channel information (corresponding to the channel bit rate after channel coding, not to be confused with the user bit rate before channel coding).

The inner convolutional coding reduces the usable number of bits to 1/2, 2/3, or 3/4 of the channel information.

The outer Reed-Solomon block coding furthermore reduces the usable number of bits about 10 %.

Subcarrier signal in time domain (1)

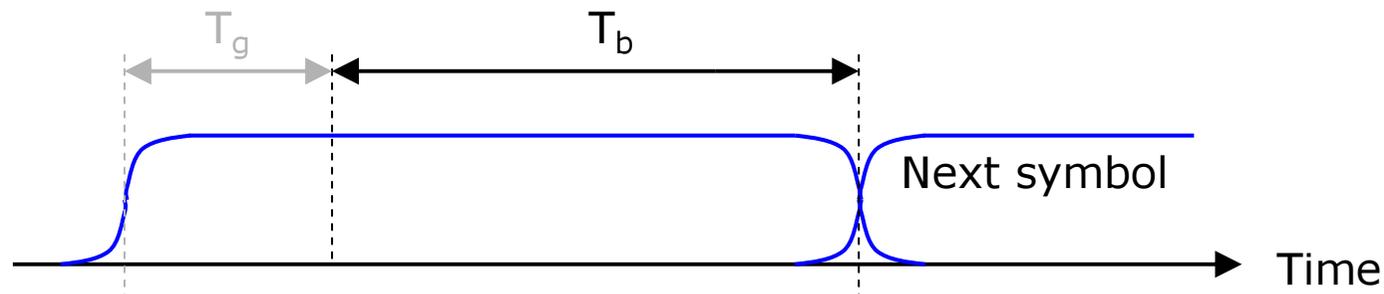Guard time for preventing
intersymbol interference

In the receiver, FFT is calculated
only during this time

T_g

T_b

Next symbol

Time

T_s
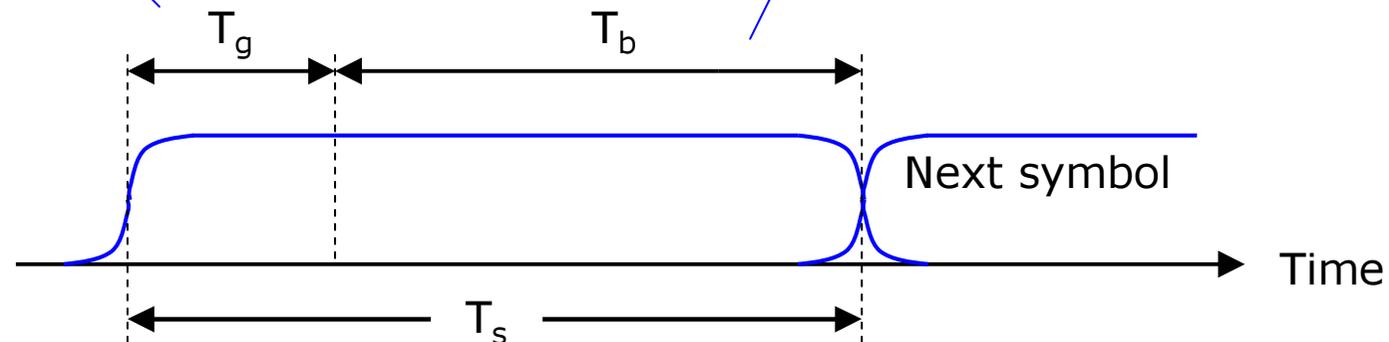
IEEE 802.16 offers four values for $G = T_g/T_b$: G = 1/4, 1/8,
1/16 or 1/32. (802.11a/g offers only one value: G = 1/4)

Subcarrier signal in time domain (2)

IEEE 802.16 offers various bandwidth choices. The bandwidth is typically an integer multiple of 1.25, 1.5 or 1.75 MHz.
(802.11a/g offers only a fixed channel bandwidth: 16.25 MHz)

Since the number of subcarriers is fixed, a certain bandwidth is translated into a certain subcarrier spacing $\Delta f = 1/T_b$.

Four primitive parameters

WirelessMAN-OFDM defines four "primitive parameters" that characterize the OFDM symbol:

The nominal channel bandwidth BW

The number of used subcarriers N_{used} = 200

The sampling factor n. This parameter depends on the bandwidth. For instance, when the bandwith is a multiple of 1.25, 1.5 or 1.75 MHz, n = 144/125, 86/75 or 8/7, respectively.

The guard time to useful symbol time ratio G.

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Derived parameters

Using the four primitive parameters shown on the previous slide, the following additional parameters can be derived:

N_{FFT} (the smallest power of two greater than N_{used}) = 256

Sampling frequency f_s = floor(n·BW/8000)x8000

Subcarrier spacing Δf = f_s/N_{FFT}

Useful symbol time T_b = 1/Δf

Guard time T_g = G·T_b

OFDM symbol time T_s = T_g + T_b.

Example

For BW = 5 MHz, BPSK, G = 1/32, calculate peak bit rate:

f_s = floor(144/125 x 5 MHz / 8000) x 8000 = 5.76 MHz

Δf = f_s/N_{FFT} = 5.76 MHz / 256 = 22.5 kHz

T_b = 1/Δf = 44.44 μs

T_g = G·T_b = 1.39 μs

T_s = T_g + T_b = 45.83 μs

86.4 info bits / OFDM symbol

Peak bit rate = (192 bits x 0.5 x 0.9) / 45.83 μs
= 1.89 Mb/s

Modulation and coding combinations

Modulation	Coding rate	Info bits / subcarrier	Info bits / symbol	Peak data rate (Mbit/s)
BPSK	1/2	0.5	88	1.89
QPSK	1/2	1	184	3.95
QPSK	3/4	1.5	280	6.00
16-QAM	1/2	2	376	8.06
16-QAM	3/4	3	568	12.18
64-QAM	2/3	4	760	16.30
64-QAM	3/4	4.5	856	18.36

Depends on chosen bandwidth (here 5 MHz is assumed)

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Example (cont.)

The peak bit rate does not take into account the MAC layer overhead (MAC PDU header and trailer) and PHY layer overhead (contention slots and burst preamble in UL, DL PHY PDU preamble and header in DL).

Consequently, the user data rate is substantially smaller (even if the SS is the only user of the WMAN).